Panel Discussion on Site Characterization of DNAPLs in Fractured Bedrock[1]

Moderator: Kathy Davies, U.S. EPA, Region 3
Kevin Farrar, New York State Department of Environmental Conservation
Kent Novakowski, Queen's University
John Williams, U.S. Geological Survey
Tom Zondlo, Shaw Group

Panel Question 1: What is the minimum investigatory program that you feel is technically defensible?

Novakowski: The answer depends on the conceptual model and how far along the investigation effort is. The minimum approach would be to develop a conceptual model using the available site-specific data and regional stratigraphic data. Then, the initial investigation should attempt to validate this model.

Zondlo: An iterative approach is necessary for a fractured rock site investigation. The first step would be to drill a sufficient number of boreholes to determine where the major fracture sets are. The second step would be more involved, but the level of effort would depend on the amount of money available. A good initial conceptual model is necessary.

Williams: I agree that the investigation approach should be phased. Develop the conceptual model and define the objectives of the investigation (e.g., locate the source or delineate the plume). Don't get caught up in defining ground-water flow *a priori* in some of these aquifer systems, because they may not be what they appear. For example, shales may be water bearing and sandstones may not. The investigation will define two gradients—chemical and hydraulic—which might not be the same.

Farrar: I would focus on finding the source and defining its volume. Also, many investigators prefer to start a drilling program with shallow boreholes and progress to deeper ones. I prefer to drill the deepest holes first to better understand the stratigraphy and better develop the conceptual model as the investigation progresses.

Novakowski: We need to recognize that for almost all fractured rock sites, the governing flow features are discrete fractures. We need to learn more about these fractures and whether or not they can be lumped together to assign an effective parameter. At some sites, there may be only a few fractures that are interconnected, which are the primary players in contaminant transport. The location of these fractures and their hydraulic properties must be identified and defined. At a more densely fractured site, you still have major processes that play like diffusion, but you can treat the fractures more as a continuum. After the first phase of a bedrock investigation, I recommend targeted drilling and surface geophysics.

Zondlo: I agree that one to three deep exploratory borings drilled in unaffected but relevant areas at the beginning of the investigation are good to define the bedrock structure. The initial borings do not have to be cored, but can be relatively inexpensive drilling with subsequent use of geophysics (including downhole video camera and flowmeters) to ascertain the fracture structure. Use the results of the initial borings and geophysics to determine the optimum locations for cored holes.

[1]The following writeup is a summary, not a transcript, of the panel session discussions.

Williams: Before drilling any boreholes, identify any existing wells in the area. Many facilities have their own production wells. These wells can be very useful in constructing a conceptual model and may be acceptable for geophysical logging, hydraulic testing, or video camera.

Panel Question 2: How do you determine the depth of interest at the beginning of an investigation?

Farrar: Look at the regional geology and any information available from wells completed in the area.

Zondlo: A lot of investigations do not occur in isolation. There may be other Superfund activities in the area that might have data relevant to your site. Also, look at the regional geology to estimate the depths to aquitards and active fracture zones, and the presence of any faults.

Novakowski: The depth of interest is always deeper than you think it is. At one site I've worked on, the upper part of the bedrock was a well-characterized granite with a downward gradient. To determine whether offsite migration might occur at depth, a deeper hole (250 feet) was drilled. A very large, weathered, sheeting fracture that provided a pathway for contaminant migration was identified. This fracture would never have been found without drilling a deep hole.

Zondlo: Valuable site information can often be obtained from unorthodox sources. For example, during the 1930s and 40s, the Tennessee Valley Authority did extensive exploration within the karst region near Huntsville, Alabama, to identify potential locations for dams. Their exploration identified a number of fracture features upstream and downstream from the site being investigated.

Panel Question 3: What role do you think domestic and municipal wells have during the initial information-gathering phase?

Williams: Municipal wells are installed to obtain the most water possible and are generally screened over a large part of the aquifer. which is useful. However, it is difficult to use municipal wells for geophysical logging because the instruments cannot be placed below the pump unless the well is closed and the pump is pulled out. However, the USGS office in San Diego has developed tools that can be snaked down a municipal well without pulling the turbine pump.

Domestic wells are much easier to access since you inconvenience one family by running tests, rather than a whole city. These wells are typically drilled to find 5 gallons per minute, however, and will probably be only as deep at the first water-bearing zone.

Farrar: Making use of existing available public supply wells to gather geophysical data is one way of obtaining relatively inexpensive subsurface information. On the other hand, some municipal wells are in terrible condition, and you risk losing your geophysical tools by putting them down these wells.

Zondlo: We have been able to get good information from domestic wells. Most of the time, people are willing to let you use their well for testing, especially if you can provide them with an alternative supply and convince them you will not harm the well.

Panel Question 4: After the information-gathering phase what hierarchy would you apply in using tools, and what are your techniques and approach?

Novakowski: Once you run the geophysics tests, the next step is to gather hydraulic information. Measurements of hydraulic head, transmissivity with depth, and borehole interconnectiveness are needed. You should not entirely rely on flowmeters to estimate flow. Generally, flowmeters only measure the flow of the most permeable features and miss the lower-flow zones that could significantly affect contaminant transport. The creation of a borehole changes the natural flow conditions. As a result, the flow that is measured in the borehole is not necessarily the flow that would occur in its absence. It is crucial that flows be measured in packed intervals and that these intervals are sufficiently dense to ensure true head and transmissivity distributions are measured, not averages.

Williams: A more detailed approach is needed when investigating near the source because minor fractures and matrix effects are a concern, not just major fractures. This approach would include borehole geophysics, hydraulic testing, and core testing for matrix diffusion.

Panel Question 5: Which hydraulic tests are the most effective and provide the most useful data?

Farrar: Pumping tests are best to determine which fractures are connected, how far away the effects reach, and how much yield a fracture set is capable of providing. I recommend conducting as many pumping tests as you can afford.

Zondlo: Flowmeter tests should be run concurrently with packer tests to better calibrate the data. Otherwise, the two methods can yield results that are orders of magnitude apart.

Williams: Injection straddle packer testing and flowmeter testing were done in the crystalline rock at the Mirror Lake site. The flowmeter tests typically identified and provided estimates of transmissivity comparable to the packer tests for those flow zones whose transmissivity were within one to two orders of magnitude of the most productive zone in the borehole.

Novakowski: Under ambient conditions, flowmeters can miss larger features in carbonate rock.

Williams: Flow zones ay be missed if flowmeter tests are only done under ambient conditions. Therefore, whenever possible, flowmeter tests should be completed under both ambient and stressed (pumped or injection) conditions.

Panel Question 6: How do you know when you have done enough to characterize a site?

Novakowski: The conceptual model ceases to change as you add more information from different sources.

Zondlo: You must balance the expense of collecting more data with the usefulness of the data in lowering uncertainty, rather than turning the project into a research effort that eliminates all uncertainty.

Novakowski: If the ground-water flow pattern is critical, you may have to characterize the site to a very large degree. You must determine how much characterization is needed to satisfy the objectives of the investigation. If the objective is to remediate a source zone, then you need to investigate on an individual connective fracture scale. To increase the likelihood of success for the remediation, you need to know how the system will behave. If you don't know this, then your remediation will likely fail.

Zondlo: There is always the issue of not being able to quantitatively demonstrate the bounds of uncertainty in fractured rock and, hence, make the argument that characterization is complete. You probably will never get completely characterize the site, and that has to be good enough.

Moderator: How does the selection of a particular remedial technology drive the site characterization process?

Farrar: The selection of the remedial technology and the site characterization process must be completely integrated.

Williams: For example, you need different characterization data if you are considering a hydraulic remedy versus a geochemical remedy.

Novakowski: You might want to start by determining where the mass might be. Look at how much was mass released and the age of the release to calculate matrix effects of the fracture system. It may turn out that the mass that is held in the rock will drive the remedial decision. Nonetheless, understanding the hydraulics is the key to the success of both hydraulic and chemical remedial technologies.

Question from audience: How do you recommend prioritizing items in budgeting?

Zondlo: Most of the cost for characterization is spent for packer testing and coring. Cored boreholes are three times the cost of air rotary boreholes. To avoid the costs of coring you could do more geophysic testing, such as using an optical televiewer. Geophysics doesn't provide as much information as coring, but it the best value. Before proposing any characterization work, you should ask yourself, "What will I learn from this, and how will it reduce the uncertainties in my remedial decisions?"

Novakowski: After evaluating all the available information, a minimum approach might be to drill three boreholes using whatever drilling method is cheapest. Apply a suite of geophysics and do multilevel completions of the boreholes. The multilevel completions will give the best information.